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ION, ELECTRON AND NEUTRAL TEMPERATURES DERIVED FROM ION COMPOSITION DISTRIBUTION

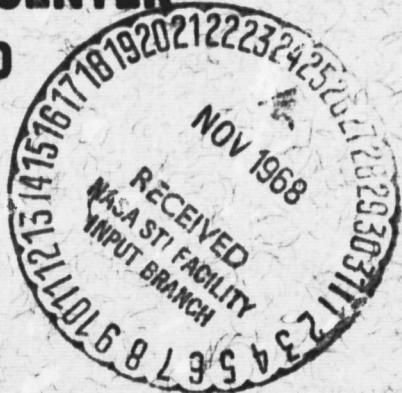
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ION, ELECTRON AND NEUTRAL TEMPERATURES DERIVED FROM ION COMPOSITION DISTRIBUTION

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Recently Brinton et al (1968) reported the positive ion mass spectrometer measurements obtained from the Geoprobe (Argo D-4 rocket) over an altitude range of 200-630 km at 1300 EST on March 2, 1966 above Wallops Island, Virginia. The ionic constituents measured were O^+ , N^+ , H^+ , He^+ , NO^+ , O_2^+ and N_2^+ (Fig. 1). The measurements showed O^+ as the major constituent throughout the altitude range. Since the distribution of each ionic species is controlled by diffusive processes at higher heights and chemical processes at lower heights with an overlap in the intermediate heights (Bauer 1964) it is possible to derive the ion, electron and neutral temperatures from the composition data using the appropriate expressions.

Under diffusive equilibrium, the distribution of an ionic species X^+ in an ion mixture having a mean ionic mass m_+ is given by (Mange 1960, Bauer 1966)

$$n(X^+) = n_0(X^+) \exp \left\{ - \left[\int_0^z \left[(m(X^+) - \frac{T_e}{T_e + T_i} m_+) \frac{g_0}{kT_i} + \frac{\partial}{\partial z'} \left(\frac{T_e + T_i}{T_e + T_i} \right) \right] dz' \right] \right\} \quad (1)$$

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where T_e = electron temperature

T_i = ion temperature (assuming all ions to be at the same temperature)

z' = geopotential height

g_o = acceleration of gravity at the earth's surface

As pointed out by Bauer (1964, 1966) an important feature of the diffusive equilibrium for ions is that, whereas the distribution of an individual ion species depends on T_e as well as T_i , the ratio of the two species in diffusive equilibrium depends on T_i only and, thus, the relative abundance of ionic species in diffusive equilibrium provides a measure of T_i .

From eq. (1) we obtain

$$\frac{\partial}{\partial z'} \ln \left[\frac{n(X_1^+)}{n(X_2^+)} \right] = \frac{m(X_2^+) - m(X_1^+)}{kT_i/g_o} \quad (2)$$

The above equation can be used to derive T_i from the height gradient of the ratio of $n(X_1^+)$ and $n(X_2^+)$, if both of them are in diffusive equilibrium. If they have not attained complete diffusive equilibrium in the region under study, the temperature derived from such a profile will be in error depending on the extent to which the distribution deviates from that of diffusive equilibrium. From the nature of distributions in Fig. 1 it appears that O^+ , H^+ , N^+ and He^+ are probably in diffusive equilibrium from 500 km upwards. From theoretical

studies it is estimated that whereas O^+ , H^+ and He^+ attain diffusive equilibrium by about 500 km or even lower altitude (Nisbet 1963, Bauer 1964, 1966; McElroy, 1965), N^+ is still under chemical-cum-diffusive control (Bauer, 1966). It is thus reasonable to proceed with the assumption that O^+ , H^+ and He^+ are in diffusive equilibrium above 500 km to determine T_i using eq. (2). In fact, even for $n(H^+)$ the theoretical scale heights calculated on the basis of diffusive equilibrium and using the temperatures and their gradients presented later, are 130 km, 180 km and 320 km which are close to the observed values of 100 km, 170 km and 320 km at altitudes of 500 km, 550 km and 600 km respectively.

The values of T_i derived from the height distributions of $n(H^+)/n(O^+)$ and $n(He^+)/n(O^+)$ using eq. (2) are shown in Fig. 2 for the height range of 350 to 600 km. It is seen that from about 450 km the T_i values derived from the two ratios are essentially the same. The mean values are $1800^{\circ}K$ at 600 km, $1500^{\circ}K$ at 550 km, $1200^{\circ}K$ at 500 km and $900^{\circ}K$ at 450 km. These values are comparable to the T_i values obtained by Thompson scatter experiment by Evans (1967) under similar conditions. The T_i values below 450 km derived from $n(He^+)/n(O^+)$ distribution are in the range of $250^{\circ}-350^{\circ}K$ and are much too low compared to neutral temperature, though the T_i values derived from $n(H^+)/n(O^+)$ are comparable to neutral temperature. This result suggests that the $n(He^+)$

distribution is not in diffusive equilibrium below 450 km while $n(O^+)$ distribution may correspond to diffusive equilibrium. The $n(H^+)$ distribution, even if it is under chemical equilibrium, may still look like that of diffusive equilibrium, since both the distributions are similar for $n(H^+)$ when it is a minor ion (Bauer 1966a).

We may utilize these values of T_i and its height variation to derive T_e as follows. The geopotential scale height H^* of the electron density distribution under diffusive equilibrium is given by

$$H^* = \frac{T_e + T_i}{\frac{g_0 m_+}{k} + \frac{\partial}{\partial z'}(T_e + T_i)} \quad (3)$$

Since H^* and m_+ can be determined from the composition data, eq. (3) may be used to derive the T_e distribution. The calculation of T_e is performed by a method of successive iteration starting from $\partial T_e / \partial z' = 0$. The T_e values thus obtained are shown in Fig. 2. They are 2900°K at 600 km, 2870°K at 550 km, 2790°K at 500 km and 2580°K at 450 km. These values are in close agreement with the measured values of T_e by the electrostatic probe experiment by Brace et al (1968) on the same flight. These experimentally measured values are also shown in Fig. 2 for comparison.

With the values of T_i , T_e , $\partial T_i / \partial z'$ and $\partial T_e / \partial z'$, thus obtained, it is possible to determine if the $n(N^+)$ distribution is in diffusive equilibrium at higher altitudes. It is found that at 600 km, the scale height of the observed distribution is 275 km whereas the diffusive equilibrium scale height is 185 km. This difference implies the lack of diffusive equilibrium. However the distribution of $n(N^+)$ can be used to calculate T_n . Bauer (1966) discussed the problem of $n(N^+)$ distribution below and above its peak and showed that, above the peak, it is controlled by production through charge transfer between He^+ and N_2 and loss through the divergence of diffusive flux, and at still higher heights, by diffusive equilibrium. Above the peak and below the equilibrium region it is approximately given by

$$n(N^+) \approx \frac{1}{K} n(He) \propto \exp(-\frac{z'}{4}) \quad (4)$$

where K (a parameter dependent on diffusion velocity) may be assumed constant. Then the $n(N^+)$ distribution follows the neutral helium distribution, which in turn, depends only on the neutral temperature. The values of T_n derived from the $n(N^+)$ distribution in the height range of 350-450 km is $760^{\circ}K$.

It is also possible to determine T_n from the $n(He^+)$ distribution in the height range of 350-400 km where it is mainly controlled by chemical processes. Under chemical

equilibrium $n(\text{He}^+)$ is given by (Bauer 1966)

$$n(\text{He}^+) = \frac{I n(\text{He})}{\gamma n(\text{N}_2)} \propto \exp\left(\frac{Z}{24}\right) \quad (5)$$

where I is the photoionization rate coefficient and γ is the charge exchange rate coefficient of He^+ with N_2 . In the above equation the charge exchange reaction of He^+ with O_2 for loss of He^+ is not considered since $n(\text{O}_2)$ is lower than $n(\text{N}_2)$ by an order of magnitude in this altitude range. Then $n(\text{He}^+)$ increases with height with a scale height corresponding to the neutral temperature and mass number 24. The value of T_n derived from $n(\text{He}^+)$ distribution in the height range of 350-400 km is 780°K . This value is very close to that derived earlier from the $n(\text{N}^+)$ distribution and is also close to the value of T_n derived from neutral N_2 distribution as measured on the same flight by Pelz and Newton (1968).

In conclusion it is noted that the ion, electron and neutral temperatures may be derived from the ion composition data in a consistent way.

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CAPTIONS FOR FIGURES

Fig. 1 Ion density distributions observed over Wallops Island, Virginia by positive ion mass spectrometer aboard the Geoprobe (Brinton et al, 1968).

Fig. 2 Ion, electron and neutral temperatures derived from ion composition data shown in Fig. 1. The T_e and T_n distributions shown by continuous lines are obtained by electrostatic probe by Brace et al (1968) and derived from neutral N_2 distribution measurements by Pelz and Newton (1968) respectively made on the same flight.

WALLOPS ISLAND, VA. MARCH 2, 1966 1800 UT 1300 EST

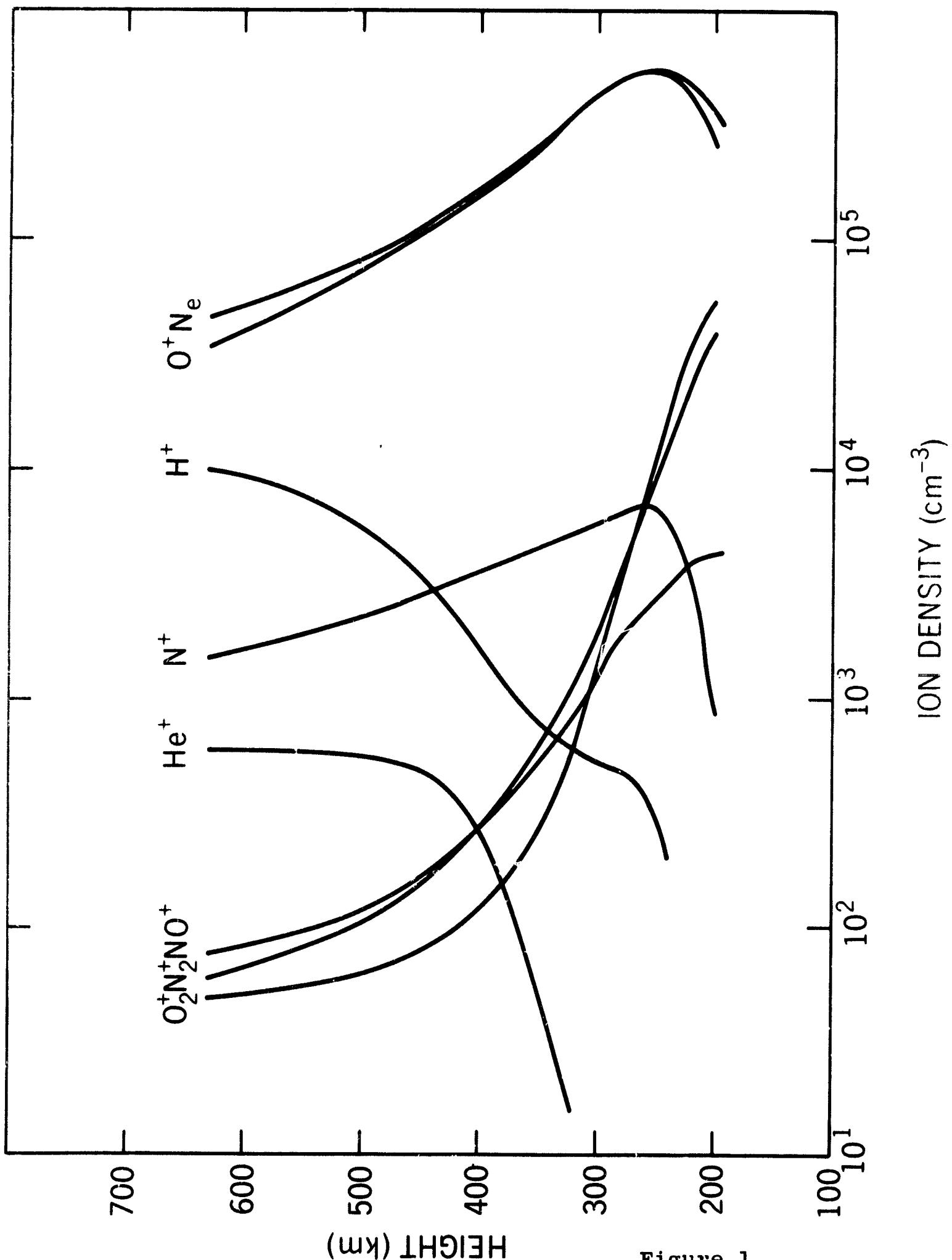


Figure 1

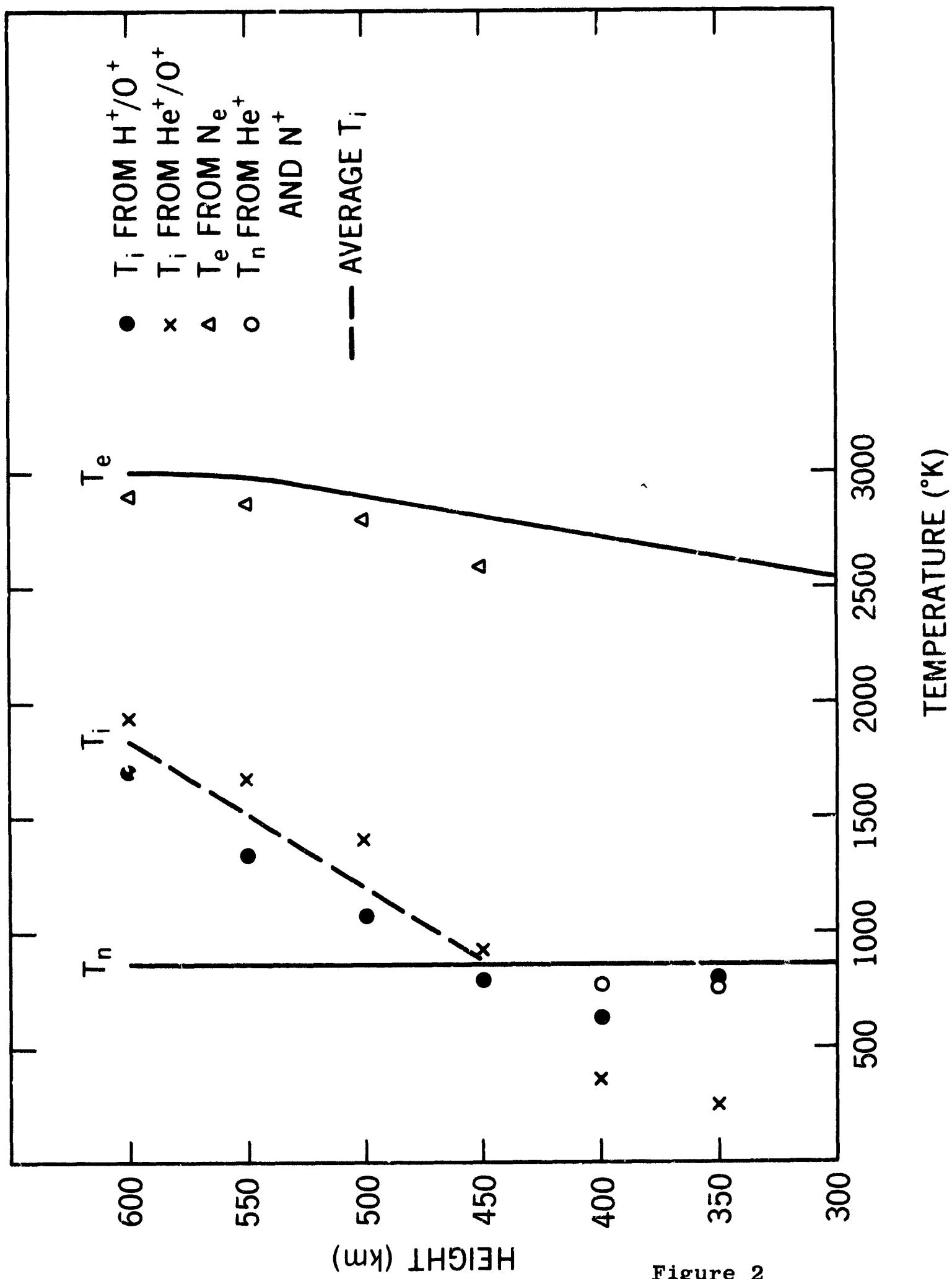


Figure 2